

Age of Barrier Canyon-style rock art constrained by cross-cutting relations and luminescence dating techniques

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Rock art compels interest from both researchers and a broader public, inspiring many hypotheses about its cultural origin and meaning, but it is notoriously difficult to date numerically. Barrier Canyon-style (BCS) pictographs of the Colorado Plateau are among the most debated examples; hypotheses about its age span the entire Holocene epoch and previous attempts at direct radiocarbon dating have failed. We provide multiple age constraints through the use of cross-cutting relations and new and broadly applicable approaches in optically stimulated luminescence dating at the Great Gallery panel, the type section of BCS art in Canyonlands National Park, southeastern Utah. Alluvial chronostratigraphy constrains the burial and exhumation of the alcove containing the panel, and limits are also set by our related research dating both a rockfall that removed some figures and the rock's exposure duration before that time. Results provide a maximum possible age, a minimum age, and an exposure time window for the creation of the Great Gallery panel, respectively. The only prior hypothesis not disproven is a late Archaic origin for BCS rock art, although our age result of A.D. ~1–1100 coincides better with the transition to and rise of the subsequent Fremont culture. This chronology is for the type locality only, and variability in the age of other sites is likely. Nevertheless, results suggest that BCS rock art represents an artistic tradition that spanned cultures and the transition from foraging to farming in the region.

Archeology is focused upon material records, contextualized in time. Rock art is a record with the potential to provide unique insight into the dynamics and evolution of culture, but it generally lacks stratigraphic or chronologic context. Interpretation of the origin and meaning of rock art is indirect at best, or simply speculative. In the case of some pictographs, pigments may include or have enough accessory carbon for accelerator mass spectrometry (AMS) radiocarbon dating (1–4). In other special situations, such as caves, minimum age constraints have been obtained by various techniques of dating material that overlies or entombs rock art (5–7). However, most rock art remains undatable and researchers rely upon stylistic comparison and indirect associations with artifacts at nearby sites (8, 9). The case in point for this study is arguably the most compelling and debated rock art in the United States—the Barrier Canyon style (BCS) of the Colorado Plateau. Previous attempts to derive an absolute chronology have failed and its age remains unknown, with widely ranging hypotheses that have remained untested until now.

The continued development of dating techniques offers new possibilities for hypothesis testing. The optically stimulated luminescence (OSL) signals from mineral grains make it possible to date the deposition of most sediment that is exposed to a few seconds of full sunlight before burial, and its use in the earth and cultural sciences has greatly increased (10, 11). Among the latest applications of OSL are techniques dating the outer surfaces of rock clasts that have become shielded from light, including those

with archaeological context (12–15). Recent work has furthermore used the “bleaching” profile of decreasing luminescence signal toward the surface of rock to estimate exposure time to sunlight (16, 17). Using these dating tools, we can constrain the age of rock art and gain new insight into past cultures and landscapes.

Here, we synthesize results from three approaches to dating the type section of BCS art, the Great Gallery in Canyonlands National Park of southeastern Utah. Through dating the full alluvial stratigraphy and a rockfall event that both have incontrovertible cross-cutting relations with the rock art, and then by determining the exposure duration of a painted rock surface, we greatly narrow the window of time when the rock art was created. These approaches do not require direct sampling of rock art and have strong potential for application to other archaeological and surface processes research. Although our results are only for the type section of BCS art, and chronological variability should be expected for the style across the region, they suggest that BCS art coincides with the transition to agriculture in the northern Colorado Plateau and may not have been limited to a specific archaeological culture.

Background

BCS rock art was recorded in the central Colorado Plateau by the Clafin Emerson Expedition in the 1920s (18) and defined as a style by Schaafsma (19). This distinctive rock art stands out from its sandstone canvas in sharp, ruddy relief and is grouped in panels of life-sized, mummy-like anthropomorphs, often accompanied by realistic representations of animals and organized in three-dimensional displays. The figures were formed

Significance

Key physical relations between the famous Great Gallery rock art panel in Utah, stream deposits, and a rockfall that removed some art, allow us to disprove all but a late Archaic hypothesis for the age of this type section of the Barrier Canyon style. Use of a new luminescence profile technique on the same rockfall furthermore outlines a window of time A.D. ~1 to 1100 when the figures could have been painted, generally more recent than expected. Our study illustrates novel and widely applicable approaches for dating rock art that do not require destructive sampling, and results suggest that Barrier Canyon rock art persisted across the transition from the late Archaic into the agrarian Fremont culture in the American Southwest.

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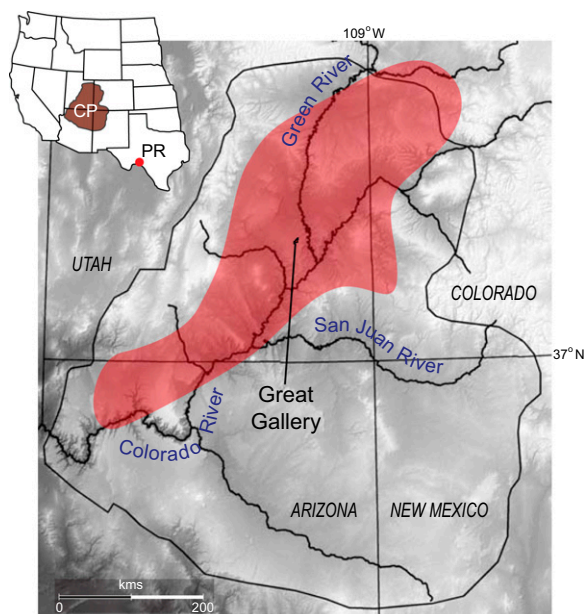


Fig. 1. Location of the Great Gallery study site near the geographic center of the region of BCS rock art (tinted in red and modified from ref. 30) in the Colorado Plateau (CP) of the western US location of the Pecos River (PR) Archaic style is marked on the *Inset* map.

by a meticulous combination of rock pecking and application of multiple pigments (19, 20). The Great Gallery is the type locality for the BCS (Fig. 1), and researchers have called it the most spectacular pictograph site in the United States (18). The many figures of the Great Gallery are arranged along the nearly 100-m length of a sandstone alcove, anchored by the distinctive “Holy Ghost and his attendants” (see Fig. 3A). Barrier Canyon rock art is commonly interpreted as shamanistic (20, 21), although this is contested (22). Similarity to other neighboring, potentially contemporaneous, styles most notably includes the Esplanade style of Grand Canyon (ref. 23; included in BCS area of Fig. 1). In the San Juan River drainage to the southwest, there are several Basketmaker II (early farmers, 1500 B.C. to A.D. 400) styles known (20), including the San Juan Anthropomorphic style, which shows elements of similarity to BCS (21). Stylistic consistency perceived between BCS panels has raised the prospect that they were painted by a single person (19). On the other hand, as BCS rock art has been increasingly documented, variability in the style has increased, with Cole (24) identifying seven variants. Panels are often located in prominent view along the walls of major canyons and generally afforded exclusive locations where superposition by later styles was avoided. However, BCS art commonly shows modification and embellishment over time, and Cole (20) argues that this shows the panels were not “frozen in time.” BCS art may in fact span considerable time and cultures, but the ability to test such ideas hinges upon building directly dated chronologies.

The age of BCS rock art has been estimated by indirect methods, including typological cross-dating, stylistic content, and by association with dated sites in the vicinity. These approaches are useful for framing models, but they cannot be empirically tested in the absence of numerical ages. In fact, there have been two prior attempts to directly date BCS art at the Great Gallery through AMS radiocarbon methods. Successful AMS dating of Fremont rock art in Canyonlands National Park (2) led to attempts to date pigment from fallen talus blocks at the Great Gallery (25). Unfortunately, there is no organic binder in the pigment, and contamination by ancient hydrocarbons and modern aqueous carbon from the sandstone bedrock produced variably old and young dates (26). A second attempt at direct

radiocarbon dating was also undermined by a lack of carbon, but one sample produced a tenuously reported and uncertain calibrated age of A.D. ~900 (26).

Although there have been unpublished arguments made for a Late Pleistocene age of BCS art based on stylistic similarities to rock art on other continents, the focus has been on an origin in early or late Archaic time (Fig. 2), before the advent of the Fremont culture in Utah (A.D. 250–1300). Similarities to clay anthropomorphic figurines from nearby Walters Cave and Cowboy Cave in the headwaters above the Great Gallery, in a radiocarbon-dated stratigraphic context of 5600–5000 B.C. (calibrated), imply an early Archaic age for BCS art (27). However, this inferred age is much earlier than most other evidence for the age of BCS, and the deposits at both caves are mixed in nature (28), highlighting the need for more direct dating of the rock art.

The most frequent chronology for BCS art places it in the late Archaic period, before the spread of farming, the bow and arrow, and the Fremont culture (19). This is based on the rarity of the bow and arrow in BCS art, superposition of Fremont style rock art over BCS art in a few cases, and similarity to the Pecos River style of the Rio Grande in western Texas (Fig. 1). Maize and the bow and arrow made their way into southern and central Utah by A.D. 1–100 (29), and the Pecos River style is directly radiocarbon dated to 2000–1000 B.C. (30), so we illustrate this hypothesis in Fig. 2 as ranging across those dates. Although late Archaic archaeological sites also have been used as evidence for the age of nearby BCS panels (19), sites from post-Archaic cultures are also common across the entire geographic range of the BCS. With a late Archaic age in mind, Cole (20) explores relationships between BCS and various Basketmaker II styles in the neighboring region, with a focus on interaction among peoples, while also noting affinities of BCS to Fremont rock art at a few sites. Thus, the cultural context of this rock art may be one of greater continuity and interaction than allowed in past conceptualizations.

A final, contrasting hypothesis is that at least some BCS art is post-Fremont (Fig. 2), associated with the Southwest kachina complex that was fully formed A.D. ~1400, based on iconography such as fox pelt pendants important in Puebloan ritual (31). Manning (31) also makes the observation that the very preservation of the delicate art, sometimes in exposed locations, argues against great antiquity.

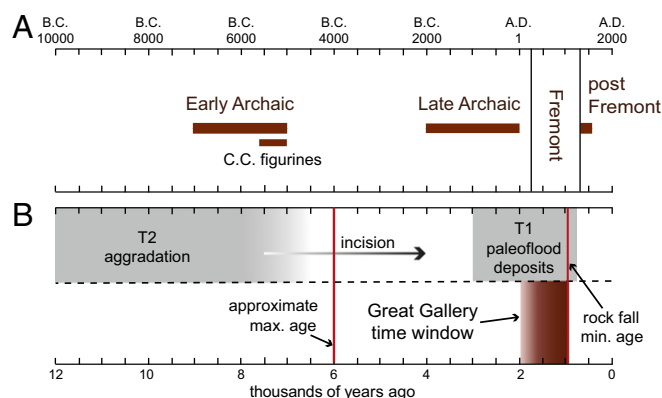


Fig. 2. Timeline spanning the past 12,000 y, illustrating the following: (A) prior hypotheses for the age and cultural affiliation of BCS rock art, notably excluding the Fremont culture, and with the Early Archaic hypothesis supported by radiocarbon constraints on Cowboy Cave (C.C.) figurines; and (B) new age constraints. The Great Gallery was created after stream incision removed T2 alluvium, which contributes to the Early Archaic hypothesis being improbable. The cross-cutting rock fall dated to A.D. ~1100 rules out the post-Fremont hypothesis. Finally, the exposure duration from OSL-profile analysis provides a more specific time window of A.D. ~1–1100 when the rock art could have been made.

Results

Maximum Age Constraint, Terrace Chronostratigraphy. The Great Gallery lies along a reach of Horseshoe–Barrier Creek that is carved in sandstone of the Jurassic Navajo Formation. Farther upstream, the relatively wide canyon bottom is marked by strath terraces and several bedrock knickpoints along the channel through the underlying Kayenta Formation, whereas in the narrower canyon through the Navajo sandstone, the drainage has a broadly convex longitudinal profile, a vegetated alluvial floodplain, and preserved fill terraces (32). Mapping reveals a series of three fluvial terraces traceable through the drainage, and the younger two, designated T1 (youngest) and T2 (older), have important physical relations to the Great Gallery (Figs. 3 and 4). The T2 terrace has a bedrock strath mantled with 0.5–1 m of clast- to matrix-supported, pebble–cobble gravel. As the drainage enters the Navajo reach, the preserved T2 deposit thickens to include more than 6 m of sandy alluvium atop the basal gravels. The inset T1 is up to 6-m thick and is a finer-grained package that occupies much of the valley bottom in the Navajo reach. It is composed of medium beds of massive to upper-plane bed, fine-medium sand interpreted as high-energy channel deposits, as well as thinly bedded, fine sand with ripple cross-stratification and thin mud drapes interpreted as slackwater deposits.

The figures of the Great Gallery are situated 8–12 m above Horseshoe–Barrier Creek in an alcove. The stream aggradation recorded in the T2 deposit throughout the reach of the canyon buried this lower alcove, as indicated by the T2 remnant next to the Great Gallery, which buttresses the bedrock wall to a height above nearly all of the rock art (Fig. 3A). The bedrock bench below the panel is the locally exhumed strath of the T2, and the remnant deposit embanked against the alcove includes interbedded lenses of bouldery talus fallen from the alcove and buried along the edge of the aggrading floodplain. The main rock art panel could not have been created until these deposits were subsequently incised by the stream, exposing the lower alcove. Nor could the rock art predate the T2 because the pigment would not have survived the burial, groundwater flow, exhumation, and then abrasion by subsequent flood discharges.

Thus, the art is incontrovertibly younger than the top of the T2 alluvium, and moreover, it postdates most of the subsequent incision to where the inset T1 flood deposits lie along the channel. A conspicuous, etched horizon in the bedrock just below the toe of the Great Gallery figures is about the height of the top of the T1, and it may represent weathering related to those flood deposits (Fig. 3A). Alternatively, the etched horizon may mark where the water-saturated basal T2 deposit used to lie, and where local dissolution of bedrock cement has subsequently promoted preferential weathering.

OSL results on sediment in Table 1 are ordered by age, and these are all in agreement with radiocarbon results in Table 2 and in stratigraphic order, as illustrated in the primary sections of T2 and T1 studied at the Great Gallery and the nearby Alcove site, respectively (presented in Figs. S1–S3). This highlights both the coherence of results and the ~5-ky hiatus marked by incision between deposition of T2 and T1 deposits. Most of the samples have dispersed and skewed equivalent-dose distributions characteristic of partial bleaching, which is to be expected with flood deposition in a canyon setting, and they are reported with analysis by a minimum-age model (MAM) (ref. 33; full results in *SI Text*, Tables S1 and S2, and Figs. S4 and S5). Two AMS radiocarbon dates from riparian-plant litter deposited within the T1 alluvium and one result from an ash and charcoal horizon in the upper T2 corroborate the OSL geochronology, with calibrated results converted to kiloannum before A.D. 2010 in Table 2 for direct comparison with OSL ages. The age results, combined with their stratigraphic context, reconstruct fluvial activity over latest Quaternary time (Fig. 4). T2 deposition in the Navajo reach corresponds to the Pleistocene–Holocene transition, 15–8 ka. The highest OSL sample (USU-671sg) lies ~0.5 below the preserved top of the T2 at the Great Gallery, and so some time after 8.01 ± 1.13 ka deposition ceased and incision began (Fig. 3A). By ~3 ka, the basal flood deposits of the T1 were emplaced at essentially the same elevations as the modern wash throughout the drainage. Erosional bounding surfaces and chronology within the T1 suggest three distinct packages of flood deposits are preserved (31), dating to ~3, 2.3–1.2, and 1.1–0.8 ka (Fig. 4 and Fig. S3).



Fig. 3. (A) Part of the Great Gallery and the geomorphic relations constraining its age. The panel must have been created after incision of the T2 exposed the lower alcove wall and before the rockfall partly removed figures. The chronostratigraphy of the T2 exposure at this locality is presented in Figs. S1–S3. Note sheeting joints producing generations of rockfalls. OSL exposure duration analysis pertains to the surface with the lower part of figures broken off. An etched horizon along the base of the panel may be either from preferential weathering where the basal gravels of the T2 used to lie or coincident with the top of former T1 flood deposits providing a platform for creating the art. (B) View downstream from the Great Gallery to another T2 fill terrace remnant just downstream, confirming aggradation to a height above the figures at the end of T2 time. The T1y is a “younger” component of the inset T1 deposit.

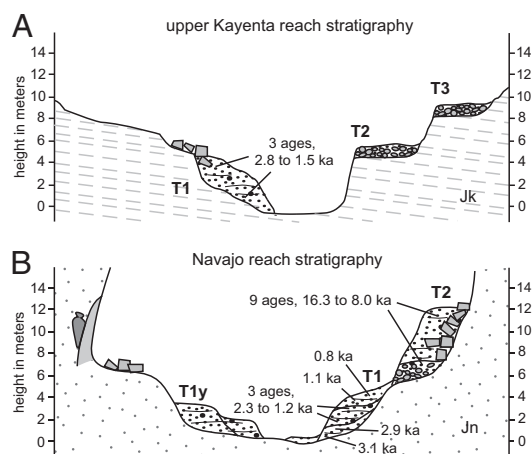


Fig. 4. Chronostratigraphic cross-sections representing (A) late Pleistocene strath terraces and late Holocene paleoflood deposits of the upper reach of Horseshoe-Barrier Creek in Kayenta Formation bedrock, which transition downstream to (B) the fill terraces preserved within the Navajo sandstone reach including the Great Gallery. Central OSL and AMS radiocarbon ages are labeled in stratigraphic position.

The Great Gallery art must be younger than the episode of incision bracketed between the T2 and inset T1, which began sometime after ~8 ka. Indeed, incision through late Pleistocene talus and alluvium, and then bedrock, must have proceeded for significant time until the lower alcove was fully exhumed and available, and we suggest a conservative maximum age constraint is ~6 ka (~4000 B.C.) (Fig. 2B). This reasoning alone makes an early Archaic (>5000 B.C.) origin for the Great Gallery improbable, and any older hypotheses are ruled out. It is, in fact, possible that formerly preserved, 3.0–0.8 ka, T1 deposits provided a standing platform for artists, marked by the etched horizon just below the figures. The position of another example of BCS art upstream along the upper drainage reach, the Blue-Eyed Moqui Princess figures, supports these Great Gallery results. Two figures at this locality are 4.5–6 m above the grade of the modern bedrock channel they overlook, and they lie in a position directly

below the local T2 strath terrace. Likewise, the toes of these figures appear abraded by later Holocene flooding.

Minimum Age from Timing of Rockfall. Another clear cross-cutting relation at the Great Gallery provides a minimum age—the rockfall that has removed parts of the figures (Fig. 3A). In related work (15), we sampled the down-facing (buried) surface of one of the talus blocks directly below this scar. This rock surface had preserved pigment of broken figures, but the sample was taken ~35 cm away from any and where no surface preparation (such as abrasion) had been done by the artists. We OSL dated both the quartz grains from the rock surface as well as the near-surface grains of loose sediment the boulder landed upon. The two OSL results are the same within error, ~800–900 y old (Tables 1 and 2) (15). Serendipitously, a third, independent age determination for the rockfall event comes from a leaf trapped between the talus boulder and underlying sediment, dated by AMS radiocarbon methods to ~900 y old, again within error of both OSL results. These three convergent dates provide a very solid minimum age constraint of A.D. 1100, the height of the Fremont culture, ruling out the post-Fremont hypothesis at this site (15) (Fig. 2B).

Exposure Duration from Bedrock Luminescence Profile. The stimulation and release of trapped charge by sunlight that resets luminescence signals happens at the surface of rocks as well as sediment. Recent work takes advantage of how this “bleaching” of rock penetrates through time into the subsurface up to a few centimeters (16, 17). The luminescence signal within the core of rocks is saturated over geologic time due to ionization from local radioactivity. The flux of sunlight at the surface penetrates and releases this trapped charge population, but this effect attenuates with depth and eventually comes into equilibrium with the dosing rate within the rock. The measured depth and form of this luminescence profile can be used to estimate the duration of surface exposure, particularly over decadal-to-millennial timescales. A primer on this method is provided in [SI Text](#) and [Fig. S6](#). Briefly, exposure time is calculated through fitting to a modeled, nested-exponential function incorporating the opacity of the rock and the local daylight spectrum and calibrated with a sample of known exposure duration (17). We have applied this technique to part of the sample of the buried, unprepared surface of the

Table 1. OSL geochronology summary

OSL sample	Unit	Location–position*	Dose rate, Gy/ky	De, Gy [†]	Age model	Age, ka [‡]
USU-186	T1	Alcove, upper	1.89 ± 0.10	1.45 ± 0.80	MAM	0.77 ± 0.21
USU-276	T1	Alcove middle, marker d	2.00 ± 0.11	2.46 ± 0.98	MAM	1.23 ± 0.28
USU-120	T1	High Cave, top	1.82 ± 0.10	2.74 ± 1.28	MAM	1.50 ± 0.40
USU-275	T1	Alcove, middle, marker c	2.17 ± 0.11	4.93 ± 1.90	MAM	2.27 ± 0.41
USU-118	T1	High Cave, base	1.57 ± 0.09	3.87 ± 2.02	MAM	2.46 ± 0.70
USU-180	T1	South Park, base	1.82 ± 0.10	5.03 ± 2.18	MAM	2.77 ± 0.79
USU-185	T1	Alcove, middle, marker b	1.83 ± 0.10	5.30 ± 1.01	MAM	2.91 ± 0.43
USU-184	T1	Alcove, base	1.03 ± 0.06	3.15 ± 1.37	MAM	3.05 ± 0.79
USU-671sg	T2	Great Gallery, section B, unit 8	3.17 ± 0.16	25.41 ± 4.43	MAM	8.01 ± 1.13
USU-670	T2	Great Gallery, section B, unit 5	1.88 ± 0.10	20.01 ± 2.48	MAM	10.66 ± 1.32
USU-179	T2	South Park, top	1.80 ± 0.10	20.88 ± 2.81	MAM	11.62 ± 1.63
USU-178	T2	South Park, middle	1.69 ± 0.09	20.46 ± 2.93	MAM	12.13 ± 1.68
USU-272	T2	Rincon, middle	1.45 ± 0.08	19.43 ± 2.97	MAM	13.38 ± 1.85
USU-668	T2	Great Gallery, section A, unit 4	1.79 ± 0.09	18.11 ± 2.45	CAM	13.50 ± 1.51
USU-181	T2	Rincon, base	1.12 ± 0.06	15.88 ± 4.18	MAM	14.22 ± 2.51
USU-669	T2	Great Gallery, section B, unit 1	1.49 ± 0.08	24.34 ± 4.91	MAM	16.31 ± 2.49
Riso	Talus	Talus rock face	1.88 ± 0.08	1.67 ± 0.07	CAM	0.89 ± 0.06
USU-847sg	Talus	Subtalus sediment	1.88 ± 0.08	1.53 ± 0.11	MAM	0.82 ± 0.07

Full OSL results are presented in [Tables S1](#) and [S2](#) and [Figs. S4](#) and [S5](#), and details of results in pink are found in ref. 15. Blue highlights key sample discussed in text.

*Chronostratigraphy of the Alcove and Great Gallery sections are presented in [Figs. S1–S3](#).

[†]OSL equivalent dose errors reported at 2-σ.[‡]OSL ages incorporate random and systematic errors reported at 1-σ.

Table 2. ^{14}C geochronology

^{14}C sample	Unit	Location–position*	Calibrated ka BP	Age, ka [†]
Beta #283086	Talus	Cottonwood leaf	0.87 ± 0.08	0.93 ± 0.08
Beta #244296	T1	Alcove, upper, detrital twigs	1.04 ± 0.10	1.10 ± 0.10
Beta #239779	T1	Alcove, middle, detrital twigs	1.49 ± 0.09	1.55 ± 0.09
Beta #280472 ^f	T2	South Park, middle, ash horizon	9.75 ± 0.16	9.81 ± 0.16

Result in pink relates to those in Table 1 and are found in ref. 15.

*Age calibrated with IntCal04 and reported in thousands of years before A.D. 2010 to match OSL. Errors reported at 2σ .

[†]Results provided by Pete Poston, Western Oregon University, Monmouth, OR.

rockfall clast at the Great Gallery, with calibration to a local Navajo sandstone sample in an analogous position with respect to aspect and shielding and with independently known exposure duration (16).

The luminescence profile of the down-facing rockfall clast has a different form (Fig. 5) because it was not only exposed to sunlight for some duration in the alcove but also subsequently buried at the foot of the Great Gallery. Thus, the bleached grains in the depth profile had been shielded, dosed, and reaccumulated a small luminescence signal. Indeed, it is that small reaccumulated signal that we measured in the outermost grains for one of the dates on the rockfall (15). Once recent dosing is accounted for, the profile analysis provides an exposure duration estimate of ~ 700 y for the fallen block (Fig. 5). A history of recurring rockfalls incrementally deepening the Great Gallery alcove is evident from both the talus interleaved in the T2 stratigraphy and the sequence of exposed sheeting joints in the sandstone wall (Fig. 3A). We therefore interpret the exposure age in terms of the timing of a penultimate rockfall, which first uncovered the rock surface about 700 y before the most recent rockfall at A.D. ~ 1100 . The uncertainty in this exposure duration result only expresses model fit and analytical error, but it confidently indicates the pigmented rock surface was subject to several centuries of sunlight exposure in the alcove, whereas exposure for over a millennium is very improbable by our analysis in Sohbaty et al. (17). Those several centuries before the rockfall represent the window of time, A.D. ~ 400 – 1100 strictly, but A.D. ~ 1 – 1100 more conservatively, when it was possible for the Great Gallery figures to be painted (Fig. 2B). This is consistent with the tentative A.D. ~ 900 AMS age of Watchman (26) as well as the preservation of the delicate rock art, suggesting it is not as old as some have hypothesized.

Discussion

Our ability to test hypotheses and understand prehistory increases with each advance in geochronology, as experienced with AMS radiocarbon dating and U-series dating of rock art (4, 7). In situations such as the Great Gallery pictographs where organic material is completely absent from pigments or contamination is an issue, or in the case of the countless petroglyphs directly etched into rock, age control has nevertheless remained elusive. This study illustrates that techniques in OSL dating can help; these have the advantage of analyzing deposits and surfaces associated with rock art, rather than destructively analyzing the art itself. Also, basic cross-cutting relations may be used more than previously recognized. It is likely there are several other situations where natural or man-made deposits, episodes of erosion, or mass movement events could provide constraints on the timing of rock art or other archaeological features. In addition, the OSL exposure dating technique is broadly applicable where estimates of rock surface exposure on decade-to-millennial timescales are needed, making it well suited for a wide range of applications in archaeology and active surface processes.

Traditional OSL dating of alluvium along the Horseshoe–Barrier drainage produces a chronostratigraphy reflecting a paleoenvironmental context important for interpretations of regional archaeology. Like other alluvial archives throughout the Colorado Plateau, our record was generated by episodes of changing sediment transport, storage, and incision, which have long been linked to changing paleoclimate, but in ways that are still poorly understood (e.g., refs. 34–37). The T2 deposit dates to the latest Pleistocene–early Holocene transition, which in this area was a time of highly variable climate, vegetation disturbance, and later, an enhanced onset of the Southwest Monsoon (38, 39). Middle Holocene incision along the drainage may be driven by the monsoon but also corresponds to a long-recognized episode of aridity (38–40). Finally, paleoflood deposits of the T1 coincide with the late Holocene increase in frontal-derived winter moisture (41) and more variable climate with episodes of drought, flooding, and arroyo cutting. These have been linked to century-scale shifts in El Niño patterns, the Medieval Warm Period (A.D. ~ 900 – 1300), and the subsequent Little Ice Age (42, 43). The Great Gallery was painted in the overall wetter and more variable late Holocene, during the transition to agrarian societies in this region, but before the shifts in settlement patterns that coincide with drought and arroyo cutting toward the end of the Medieval Warm Period (43).

The time frame for the Great Gallery type locality provides a new context for BCS rock art within not only the paleoenvironmental record, but also, of course, the archaeology of the region. The painting of the Great Gallery occurred during a window between late Archaic (BM II) time, around A.D. 1, through the introduction of maize and the bow and arrow to Utah, and on to the peak of the Fremont culture A.D. ~ 1100 . The Archaic roots of the Fremont were noted long ago, and a variety of evidence indicates continuity between Archaic foragers and Fremont agriculturalists between A.D. 1 and 400 (29). It appears that, at that time, immigrant populations brought agriculture and village lifeways from the Four Corners region to north of the Colorado River and a landscape already inhabited by forager populations (44). There is some evidence for multiple ethnic/language groups among these immigrants, and the Fremont emerged from this diversity and interaction, with their cultural variation expressed in Fremont rock art (19, 44).

Likewise, as rock art scholars have documented increasing variability in BCS art and noted overlaps of style and execution with neighboring rock art, it has been suggested that BCS art was a living tradition built over time as well as space (20). There are contrasts

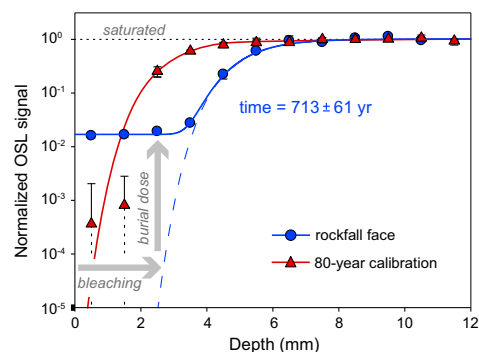


Fig. 5. Normalized OSL signal with depth into the buried face of the rockfall clast (blue data points and model-fit line) and the local calibration sample with known exposure age (red data points and model-fit line), reported with analytical error, modified from ref. 16. During burial and dosing, the OSL signal accumulated over time toward a saturated level set by crystallographic characteristics. During exposure, liberation (bleaching) of the OSL signal penetrates into rock at a rate that decreases exponentially. The rock surface some Great Gallery figures were painted upon had been exposed for only several centuries (713-y model result from bleaching to dashed blue line) before the burial dose accumulated after the dated rockfall.

between Fremont and BCS rock art, and although our current chronology from part of the Great Gallery panel cannot specifically decipher whether BCS just preceded or coexisted with Fremont rock art, our results are consistent with there being multiple rock art traditions within the greater Fremont temporal window. If the BCS was established before the origins of the Fremont, then it is nevertheless possible that it persisted during the development of distinctively Fremont rock art styles. Rather than an exclusive match of rock art styles to particular archaeological cultures, BCS rock art may have endured in the midst of human mobility, interaction, and new traditions appearing. As more age constraints are obtained on BCS panels, we can test whether it was produced over a considerable span of time. If so, then it was made by peoples of contrasting heritage, but who nevertheless maintained a common tradition, expressed in the compelling iconography of the BCS.

Methods

Details of OSL methods, data, and analysis are found in *SI Text*, *Tables S1* and *S2*, and *Figs. S4–S6*, including a primer on the exposure profile method. Full data and analysis for the rock surface and rock profile dating results are found in refs. 15 and 16, respectively. For the OSL alluvial chronology presented here, samples were collected in steel tubes, and representative sediment was collected from within 30 cm for determination of dose rate. The bulk concentration of ^{40}K , ^{87}Rb , ^{238}U , and ^{232}Th were measured using mass spectrometry, and dose rates

incorporating this, estimated water content history, and cosmic contribution were calculated using the conversion factors of ref. 45. Optical measurements were conducted on a target grain size fraction of quartz isolated and etched following routine procedures. Measurements with RISO TL/OSL-DA-20 readers followed the single-aliquot regenerative protocol of Murray and Wintle (46), with the reported age calculated from >20 aliquots that passed criteria of signal reproducibility and reliability.

The equivalent-dose distributions of most alluvial samples were analyzed with a MAM (33) to statistically isolate data from mineral grains that were completely bleached before burial. Use of the MAM was based partly on the dispersion and skewness of equivalent-dose distributions (*SI Text*), but also by requirements of field-stratigraphic coherence and correlation to AMS radiocarbon dates. Sample USU-671sg, which provides a maximum age constraint, was analyzed using more intensive and accurate single-grain measurements (47) and calculated using a MAM. Total 1σ errors reported on all OSL ages include random and systematic errors from equivalent-dose scatter, uncertainties in the calculation of environment dose rates, and instrumental error.

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